2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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An Evaluation of Pathogen Removal in Stormwater Best Management Practices in Charlotte and Wilmington, North Carolina

J.M. Hathaway

N.C. State University, Campus Box 7625, Raleigh, NC, 27695, jon_hathaway@ncsu.edu

W.F. Hunt

N.C. State University

J.D. Wright

N.C. State University

S. Jadlocki

City of Charlotte – Storm Water Services

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Abstract. *Pathogens are a target pollutant in many parts of North Carolina, particularly in areas that drain to shellfish waters. Standards have been established for pathogen indicators in fresh water (200 cfu/ 100 ml for fecal coliform, 126 col/100 ml for E. coli, and 33 cfu/100 ml for enterrococcus) and marine waters (35 cfu/100 ml for enterrococcus) being used as full body recreational areas in an attempt to reduce public health risks. Runoff samples collected from urbanized watersheds often are high in pathogenic indicator bacteria, leading to the need for treatment (Bright, 2007; MOAWMS, 2003; Schoonover and Lockacy, 2006). However, there is little peer reviewed literature regarding stormwater Best Management Practice (BMP) treatment of pathogens. The NCSU Biological and Agricultural Engineering Department monitored 14 stormwater BMPs, 9 in Charlotte, NC, and 5 in Wilmington, NC, to evaluate their efficiency with* *respect to indicator bacteria removal. The study locations included 2 bioretention areas, 4 stormwater wetlands, 3 wet ponds, 2 dry detention, and 3 proprietary BMPs.*

Keywords. Stormwater, BMP, bacteria, pathogens,

Introduction

Pathogen pollution is a source of water quality degradation which impedes the initiative of the Clean Water Act "to restore and maintain the chemical, physical, and biological integrity of the nation's waters." In the United States Environmental Protection Agency's (USEPA, 2002) National Water Quality Inventory in 2000, 13% of the river and stream miles that were surveyed were impacted by bacteria (pathogens). In light of this impairment of surface waters, Total Maximum Daily Loads (TMDLs) are established to aid in reaching water quality goals in targeted watersheds.

Stormwater runoff is a transport mechanism for pathogens to surface and coastal waters. Pathogens come from both human and animal (domestic and wild) sources, and are transported through rainfall-runoff processes to nearby water bodies. A study by the Municipality of Anchorage Watershed Management Services (MOAWMS, 2003) indicated that fecal coliform loading is high in runoff that originates from landscaped areas associated with densely urbanized areas that are drained via curb and gutter conveyances. Schoonover and Lockacy (2006) found similar results in a study of 18 mixed land use watersheds in West Georgia, and determined that watersheds consisting of greater than 24% imperviousness exhibit higher fecal coliform concentrations than watersheds with impervious percentages less than 5% during both base flow and storm flow. Further, stormwater runoff from urbanized, coastal areas have often exceeded fecal counts of 20,000 cfu/ 100 ml (Bright 2007).

To test for the presence of harmful pathogens in surface waters, indicator species are used. Various indicator species have been used to assess water quality degradation including: total coliform, fecal coliform, *Escherichia coli* (*E. coli)*, and enterococci. In 1986, the EPA's Ambient Water Quality Criteria for Bacteria report (USEPA, 1986) discusses the merits of these various indicator species, and sets target concentrations for indicator bacteria. This criteria states that for fresh waters designated for use as full body contact recreational waters, the geometric mean over a 30 day period should not exceed 126 col/100 ml for *E. coli* and should not exceed 33 col/100 ml for enterococci. For marine waters designated for use as full body contact recreational waters, the geometric mean over a 30 day period should not exceed 35 col/100 ml for enterococci.

Urban stormwater is commonly treated by way of stormwater Best Management Practices (BMPs), each of which provides some combination of natural treatment mechanisms. These BMPs include wet ponds, dry detention basins, wetlands, bioretention areas, and proprietary devices. Although BMPs have been studied in detail for many pollutants, little peer-reviewed literature is available which documents their ability to remove or inactivate pathogens. Nine sites in Charlotte, NC, and 5 sites in Wilmington, NC, were monitored to determine pathogen removal efficiency.

Site Descriptions

The stormwater BMPs evaluated in this project were monitored as part of the Charlotte – Mecklenburg Stormwater Services (CMSS) Pilot BMP Program and the Burnt Mill Creek Watershed Restoration program in Wilmington, NC. As part of these studies, grab samples were taken and analyzed for both fecal coliform and *E. coli* from 9 stormwater BMPs in Charlotte, NC, and for *E. coli* and enterococcus at 5 stormwater BMPs in Wilmington, NC. In Charlotte, data were gathered from two dry detention basins, one wet pond, two stormwater wetlands, one bioretention area, and three proprietary BMPs. In Wilmington, data were gathered from two wet ponds, two stormwater wetlands, and one bioretention area. The Wilmington bioretention area was hydraulically separated into two cells, one two feet deep and one 4 feet deep. Although data collection has been completed in Charlotte, the study in Wilmington was ongoing at the time of this publication. The characteristics of the BMPs from each city are given in Table 1.

Table 1: BMP and Watershed Characteristics

Site (Charlotte)	**Watershed Size (ha)**	**Description**	**Estimated Curve Number**
Dry Detention 1	2.4	Office Park - Buildings and Parking	85
Dry Detention 2	1.5	Office Park - Buildings and Parking	94
Wet Pond	48.6	Residential	75
Wetland 1	21	Residential	80
Wetland 2	6.4	Residential and School	83
Bioretention	0.4	Municipal Parking Lot	98
Proprietary 1	0.3	Bus Maintenance Facility – Parking and Overhead Shelters	98
Proprietary 2	0.9	Bus Maintenance Facility – Parking and Overhead Shelters	98
Proprietary 3	0.9	Bus Maintenance Facility – Parking and Overhead Shelters	98
Site (Wilmington)	**Watershed Size (ha)**	**Description**	**Estimated Curve Number**
Bioretention	0.14	Parking Lot	98
Wetland 1	12.7	School Parking Lot and Fields	73
Wetland 2	2.0	Multi Family Residential	77
Wet Pond 1	4.7	Commercial	81
Wet Pond 2	7.2	Single Family Residential	70

Monitoring Methods

Charlotte

As part of the Charlotte Pilot BMP Program, grab samples were utilized due to the small sample hold times required of bacteriological samples (USEPA, 2002). Grab samples were collected from the inlet and outlet of each BMP while flow was occurring from a given rain event. The samples were tested for fecal coliform and *E. coli*. Monitoring at the various sites in Charlotte occurred between March 2004 and October 2006; however, the monitoring period and number of samples collected at each site varied (Table 2).

Wilmington

Grab samples were also collected at each site in Wilmington, NC, beginning in August of 2007. The samples from Wilmington were analyzed for enterococcus and E. coli. Enterococcus has proven to be a more reliable indicator species in environments with higher salinity (USEPA, 1986). Table 3 shows the number of samples collected at each site. Because of the abnormally low rain fall in 2007 and the beginning of 2008 few samples were collected and therefore, no analysis was possible. Sample collection continued as of the time of this publication.

Table 2: Monitoring Period and Number of Samples Taken at Each Study Location

Site	Start	End	Number of Sample Tested For Fecal Coliform	Number of Samples Tested For *E. coli*
Dry Detention 1	Feb-05	Jul-06	9	9
Dry Detention 2	Jan-05	Dec-05	12	12
Wet Pond	Aug-04	Apr-06	14	10
Wetland 1	Mar-04	Jun-05	9	6
Wetland 2	Sep-04	Dec-05	15	10
Bioretention	Aug-04	Mar-06	19	14
Proprietary 1	Oct-05	Oct-06	7	7
Proprietary 2	Oct-05	Oct-06	6	6
Proprietary 3	Oct-05	Oct-06	6	6

Table 3 Number of samples taken at each Wilmington Study Site

Site (Wilmington)	Number of *E. coli* Samples	Number of *enterococcus* Samples
Bioretention	2	4
Wetland 1	3	6
Wetland 2	3	3
Wet Pond 1	3	6
Wet Pond 2	0	0

Data Analysis

To adequately describe the bacteria sequestration and removal performance of each BMP, various analyses were performed. This included a calculation of concentration reduction efficiency. The concentration reduction efficiency (CR) was calculated by averaging the concentration of the influent samples and the effluent samples that were collected and using them in equation 1 below:

Equation 1: CR = 1 – (average outlet concentration / average inlet concentration)

An analysis of effluent concentrations was also performed. The geometric mean effluent concentrations of fecal coliform and *E. coli* leaving each site were compared to the maximum 30-day geometric mean for each indicator as established by the USEPA for full body contact (EPA, 1986; EPA 1976). This will aid in evaluating not only the efficiency of pathogen removal for each system, but also the practicality of using stormwater BMPs to improve runoff from urban watersheds to pathogen concentrations equal to or below targeted concentrations.

Additional analysis was performed only on the Charlotte data due to the small sample set available for the Wilmington study at the time of this document. Data were transformed into the correct distribution and were tested for significant differences between the influent and effluent bacteria concentrations using a non-parametric Wilcoxon signed rank test.

Results and Discussion

Charlotte

Table 4 presents the results for fecal coliform and table 5 presents the results for *E. coli* for the BMPs studied in Charlotte, NC.

Table 4: Fecal Concentration Reduction Efficiency for BMPs in Charlotte, NC.

BMP Type	Geometric Mean Influent (col/100ml)	Geometric Mean Effluent (col/100ml)	Efficiency Fecal Coliform (%)	% of effluent samples under 200 col/100 ml
Dry Detention 1	1985	2873	-3%[1]	0
Dry Detention 2	1327	1590	-21%[1]	0
Wet Pond	9033	2703	57%	7
Wetland 1	9560	184	99%[2]	56
Wetland 2	8724	3874	70%[2]	13
Bioretention	2420	258	69%[2]	74
Proprietary 1	667	277	77%	43
Proprietary 2	235	368	-169%[1]	50
Proprietary 3	1472	2379	-381%[1]	0

1: Negative values indicate an increase in concentration

2: Significant reduction between the influent and the effluent

Table 5: *E. coli* Concentration Reduction Efficiency for BMPs in Charlotte, NC.

BMP Type	Geometric Mean Influent (MPN/100ml)	Geometric Mean Influent (MPN/100ml)	Efficiency *E. coli* (%)	% of effluent samples under 126 MPN/100 ml
Dry Detention 1	915	1121	5%	0
Dry Detention 2	655	658	14%	8
Wet Pond	2122	1153	18%	10
Wetland 1	2400	106	92%[2]	33
Wetland 2	1295	864	22%	10
Bioretention	241	20	71%[2]	86
Proprietary 1	36	37	-13%[1]	71
Proprietary 2	4	14	-186%[1]	83
Proprietary 3	183	196	-96%[1]	50

1: Negative values indicate an increase in concentration

2: Significant reduction between the influent and the effluent

Any pathogen increase is potentially due to either animal activity or from bacteria reproducing within the BMPs. For the majority of BMPs, a similar reduction (or addition) in concentration was noted for both fecal coliform and *E. coli*; however, some BMPs exhibited dramatically different concentration reductions for these two indicators. This was possibly due, in part, to the difference in the number of samples taken for each pathogen at a given site; however, even for sites with the same number of fecal coliform and *E. coli* samples, variations in the CR calculated for each pathogen existed (such as proprietary 1). This indicates that data generated for BMP removal of fecal coliform may not be applicable to BMP removal of *E. coli*.

For fecal coliform, the wet pond, wetland 1, wetland 2, bioretention area, and proprietary 1 exhibited greater than 50% removal. The high fecal coliform removal determined for wetland 1 and wetland 2, 99% and 70%, is similar to that found by Birch et al. (2004). Conversely, only one of the three wet ponds studied by Mallin et al. (2002) showed fecal coliform removal equal to or greater than 70%. For *E. coli*, only wetland 1 and the bioretention area provided high (> 50%) concentration reductions. It should be noted that a small sample set and low influent concentrations may have influenced the proprietary devices with respect to pathogen removal.

Overall, wetland 1 and the bioretention proved most proficient at reducing influent concentrations of both kinds of bacteria. Each practice had a substantial amount of sun exposure, likely leading to higher die off rates. Additionally, stormwater wetlands and bioretention areas facilitate sediment removal through sedimentation and, in the case of bioretention, filtration and drying.

Wilmington

Enterrococcus data is presented in table 6 for the BMPs studied in Wilmington, NC.

Table 6: Enterrococcus Concentration Reduction Efficiency for BMPs in Wilmington, NC.

BMP Type	Number of Samples	Geometric Mean Influent (CFU/100ml)	Geometric Mean Influent (CFU/100ml)	Efficiency enterrococcus (%)	Number of effluent samples under 33 CFU/100 ml
Bioretention (2 ft depth)	4	269	843	-76%	0
Bioretention (4 ft depth)	4	269	151	-1%	2
Wetland 1	6	1171	912	6%	0
Wetland 2	3	2014	194	93%	1
Wet Pond 1	6	468	366	49%	2
Wet Pond 2	0	n/a	n/a	n/a	n/a

No statistical analysis was preformed on the Wilmington data due to the limited number of samples collected. Limited data also make trends in data difficult to observe. Additional data collection will potentially result in a better understanding of the effectiveness of the Wilmington BMPs in regard to pathogen removal. This preliminary data seems to support the variable performance that initial studies have shown with respect to BMP pathogen removal as reported by USEPA (2003).

Conclusions

The results of this study support the literature that urban watersheds are a non-point source of bacterial pollution in surface waters. Even in watersheds consisting primarily of parking lots, concentrations of indicator bacteria entering BMPs can be higher than government assigned maximum values. Unfortunately, there are limited data regarding bacteria removal in the stormwater BMPs commonly used to treat runoff from these urban watersheds.

This study suggests that some stormwater BMPs may sequester and remove bacteria. In particular, bioretention areas and wetlands showed promise in Charlotte, NC. The Charlotte bioretention area significantly ($P<0.05$) reduced both fecal coliform and *E. coli* concentrations from the inlet to the outlet with a concentration reduction efficiency of 69% and 71%, respectively. The Charlotte wetland 1, which performed better of the two wetlands monitored in Charlotte, was atypical due to its lack of vegetated growth. The shallow water depths present in wetland 1 (15 – 45 cm) and minimal vegetative coverage led to more sun exposure than would normally be expected in a stormwater wetland. This high sun exposure likely led to increased pathogen inactivation and removal by way of treatment by ultraviolet light. If the proper environment exists, it seems possible that stormwater BMPs can be sources of pathogens. This may be due to both animal activity and to pathogen persistence and regeneration within BMPs. This was potentially the case for the two dry detention basins in Charlotte.

In the Charlotte study, positive concentration reductions were achieved by BMPs for both fecal coliform (5 of 9 BMPs) and *E. coli* (6 of 9 BMPs). However, further study is necessary to determine if the effluent of various stormwater BMPs can reach USEPA targeted values and to determine which treatment mechanisms are most crucial in designing stormwater BMPs for pathogen removal. Additional study is also recommended for proprietary systems with higher influent concentrations of fecal coliform and *E. coli* over a larger number of events.

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